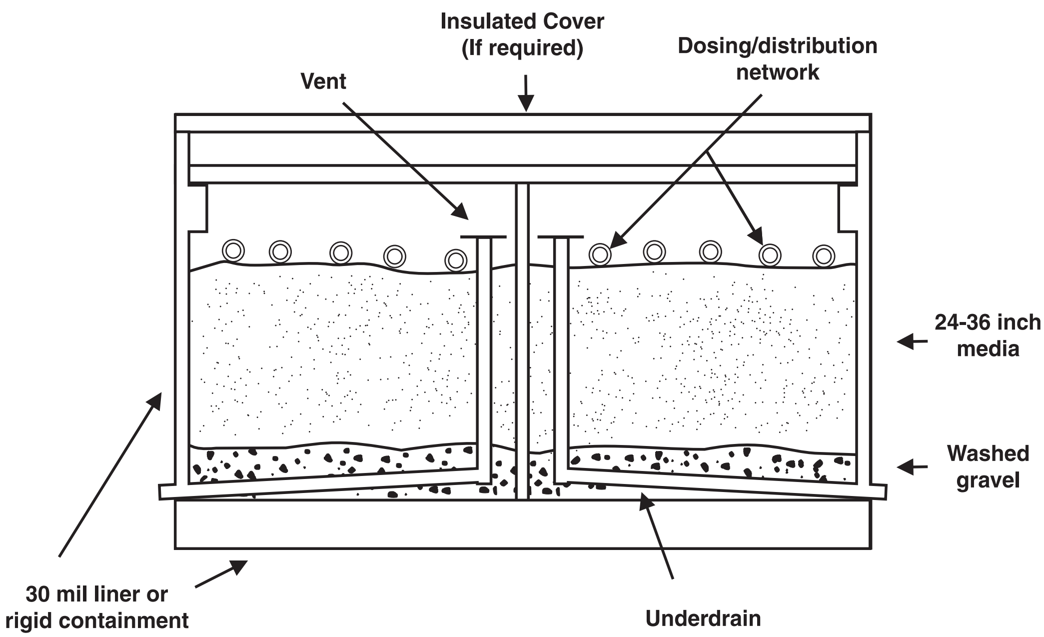
Onsite Wastewater Treatment Systems Technology Fact Sheet 10

Intermittent Sand/Media Filters

Description

The term *intermittent sand filter* (ISF) is used to describe a variety of packed-bed filters of sand or other granular materials available on the market. Sand filters provide advanced secondary treatment of settled wastewater or septic tank effluent. They consist of a lined (e.g., impervious PVC liner on sand bedding) excavation or structure filled with uniform washed sand that is placed over an underdrain system (see figure 1). The wastewater is dosed onto the surface of the sand through a distribution network and allowed to percolate through the sand to the underdrain system. The underdrain system collects the filter effluent for further processing or discharge.

Figure 1. Generic, open intermittent sand filter



Sand filters are aerobic, fixed-film bioreactors. Other treatment mechanisms that occur in sand filters include physical processes, such as straining and sedimentation, that remove suspended solids within the pores of the media. Also, chemical adsorption of pollutants onto media surfaces plays a finite role in the removal of some chemical constituents (e.g., phosphorus). Bioslimes from the growth of microorganisms develop as films on the sand particle surfaces. The microorganisms in the slimes absorb soluble and colloidal waste materials in the wastewater as it percolates over the sand surfaces. The adsorbed materials are incorporated into a new cell mass or degraded under aerobic conditions to carbon dioxide and water.

Most biochemical treatment occurs within approximately 6 inches of the filter surface. As the wastewater percolates through this layer, suspended solids and carbonaceous biochemical oxygen demand (BOD) are removed. Most suspended solids are strained out at the filter surface. The BOD is nearly completely removed if the wastewater retention time in the sand media is sufficiently long for the microorganisms to absorb wastewater constituents. With depleting carbonaceous BOD in the percolating wastewater, nitrifying microorganisms are able to thrive deeper in the surface layer where nitrification will readily occur.

Chemical adsorption can occur throughout the media bed. Adsorption sites in the media are usually limited, however. The capacity of the media to retain ions depends on the target constituent, the pH, and the mineralogy of the media. Phosphorous is one element of concern in wastewater that can be removed in this manner, but the number of available adsorption sites is limited by the characteristics of the media.

The basic components of intermittent sand filters include a dosing tank, pump and controls (or siphon), distribution network, and the filter bed with an underdrain system (see figure 1). The wastewater is intermittently dosed from the dosing tank onto the filter through the distribution network. From there, it percolates through the sand media to the underdrain and is discharged. On-demand dosing is usually used, but timed dosing is becoming common.

There are a large number of variations in ISF designs. For example, there are different means of distribution, underdrain designs, housing schemes and, most notably, media choices. Many types of media are used in single-pass filters. Washed, graded sand is the most common. Other granular media used include gravel, crushed glass, and bottom ash from coal-fired power plants. Foam chips (polystyrene), peat, and coarse-fiber synthetic textile materials have also been used. These media are generally restricted to proprietary units. System manufacturers should be contacted for application and design using these materials.

There are also related single-pass designs, which are not covered in this fact sheet. These include lateral flow designs and upflow-wicking concepts, both of which use physical removal concepts closer to the concepts described in the fact sheet on anaerobic upflow filters and vegetated submerged beds. These processes are not discussed herein but may exhibit some pollutant removal mechanisms that are described here. Simple gravity-fed, buried sand filters are not discussed because their performance history is unsatisfactory.

Applications

Sand filters can be used for a broad range of applications, including single-family residences, large commercial establishments, and small communities. Sand filters are frequently used to pretreat septic tank effluent prior to subsurface infiltration onsite where the soil has insufficient unsaturated depth above ground water or bedrock to achieve adequate treatment. They are also used to meet water quality requirements (with the possible exception of fecal coliform removal) before direct discharge to a surface water. Sand filters are used primarily to treat domestic wastewater, but they have been used successfully in treatment trains to treat wastewaters high in organic materials such as those from restaurants and supermarkets. Single-pass ISF filters are most frequently used for smaller applications and sites where nitrogen removal is not required. However, they can be combined with anaerobic processes to reduce nitrogen significantly. Many studies have shown that ISF-treated onsite wastewaters can reduce clogging of the infiltrative surface by many times when compared with septic-tank effluents. However, be careful to evaluate the overall loading of pollutants and pathogens to the underlying aquifer and nearby surface waters before considering significant SWIS sizing reductions.

Design

ISF filter design starts with the selected media. The media characteristics determine the necessary filter area, dose volumes, and dosing frequency. Availability of media for a specific application should be determined before completing the detailed design. Typical specifications, mass loadings, and media depths are presented in table 1. The sand or gravel selected should be durable with rounded grains. Only washed material should be used. Fine particles passing the U.S. No. 200 sieve (less than 0.074 mm) should be limited to less than 3 percent by weight. Other granular media that have been used are bottom ash, expanded clay, expanded shale, and crushed glass. These media should remove BOD and TSS similar to sand and gravel for similar effective sizes, uniformity, and grain shape. Newer commercial media such as textile materials have had limited testing, but based on early testing should be expected to perform as well as the above types.

Traditionally, sand filters have been designed based on hydraulic loadings. However, since these filters are primarily aerobic biological treatment units, it is more appropriate that they be designed based on organic loadings. Unfortunately, insufficient data exist to establish well-defined organic loading rates. Experience presently suggests that BOD_5 loadings on sand media should not exceed about 5 lb/1,000 ft^3 per day (0.024 kg/m^2 per day) where the effective size is near 1.0 mm and the dosing rate is at least 12 times per day.

Higher hydraulic and organic loadings have been described in several studies, but the long-term viability of the systems loaded at those higher organic loads has not yet been fully verified. The values in the table are thus considered conservative and may be subject to increases as more quality-assured data become available.

Table 1. Specifications, mass loadings, and depth for single-pass intermittent sand filters

Design parameter	Typical design value
Material	Durable, washed sand/gravel with rounded grains
Specifications	
Effective size	
Sand	0.25–1.00 mm
Gravel	N/A
Uniformity coefficient	< 4
Percent fines (passing 200 sieve or < 0.074 mm)	≤ 3
Depth	2 to 3 ft
Mass loadings	
Hydraulic loading [a]	
Sand	1–2 gpd/ft^2
Gravel	N/A
Organic loading [b]	
Sand	5 lb BOD_5/1,000ft^2-d
Gravel	N/A
Underdrains	
Slope	0–0.1%
Size	3–4 in. dia.
Dosing	
Frequency	12–24 times per day
Dosing tank	
Volume	0.5–1.5 times design daily flow

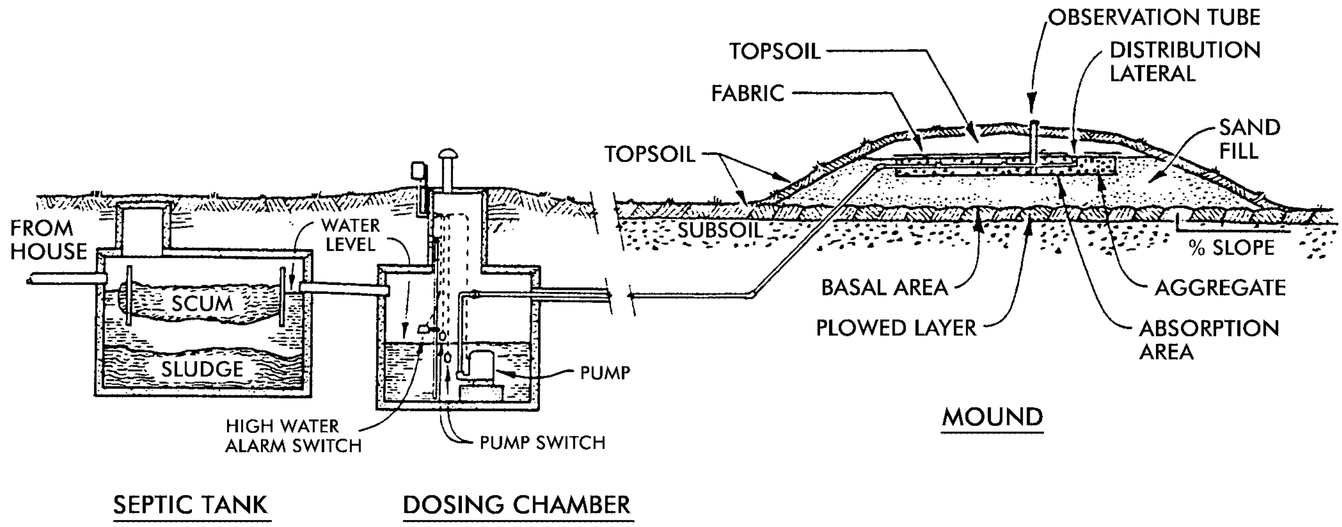
[a] 1 gpd/ft^2 = 4 cm/day = 0.04 m^3/m^2 per day
[b] 1 lb BOD/1000 ft^2 per day = 0.00455 kg/m^2 per day

Dosing volume and frequency have been shown to be the critical design variables. Small dose volumes are preferred because the flow through the porous media will occur under unsaturated conditions with higher moisture tensions. Better wastewater media contact and longer residence times occur under these conditions. Smaller dose volumes are achieved by increasing the number of doses per day. It has been suggested that each dose should be ≤0.5 cm (based on media surface perpendicular to infiltration direction) to fully nitrify the effluent in an ISF. This would limit maximum daily hydraulic loading to 12 cm/d, or 3 gpd/ft^2, if the maximum frequency of daily dosing is accepted as 24 (or hourly) as supported by the literature. Media characteristics can limit the number of doses possible. Reaeration of the media must occur between doses. As the effective size of the media decreases, the time for drainage and reaeration of the media increases.

Distribution network characteristics will also limit the number of doses possible. The primary characteristics are the volume, pressure, orifice sizes, and spacing. To achieve uniform distribution over the filter surface, minimum dose volumes are necessary and can vary with the distribution method selected. Therefore, if the dose volume dictated by the distribution network design is too high, the network should be redesigned. Since the dose volume is a critical operating parameter, the method of distribution and design of the distribution system should be considered carefully.

Distribution methods used include rigid pipe pressure networks with orifices or spray nozzles, drip distribution, and surface flooding, which is no longer recommended for small ISFs (see chapter 4). Rigid pipe pressure networks are the most commonly used method. Both orifices and spray nozzles are used. The use of spray nozzles is usually limited to recirculating filters because nozzle fouling from suspended solids is less likely than with undiluted septic tank effluent. Since the minimum dose volume required to achieve uniform distribution is five times the rigid pipe volume, the filter can be divided into multiple cells that are loaded individually so the distribution networks can be smaller to reduce the dose volume needed for uniform distribution. Optimum designs minimize the dose each time the system is dosed. Drip distribution is being used increasingly because the minimum dose volumes are much less than the volumes of rigid pipe networks.

Figure 2. ISF constructed in a mound with direct subsurface infiltration



Source: Converse and Tyler, 1998.

The underdrain system is placed on the floor of the tank or lined excavation. Ends of the underdrains should be brought to the surface of the filter and fitted with cleanouts that can be used to clean the biofilms underdrain, if necessary. The underdrain outlet is cut in the basin wall such that the drain invert is at the floor elevation and the filter can be completely drained. The underdrain outlet invert elevation must be sufficiently above the recirculation tank inlet to accommodate a minimum of 0.1 percent slope on the return line and any elevation losses through the flow splitting device. The underdrain (usually 1.25- to 2.0-inch PVC, class 200 [minimum]) is covered with washed, durable gravel to provide a porous medium through which the filtrate can flow to the underdrain system. The gravel should be sized to prevent the filter medium from mixing into the gravel, or a layer of 1/4- to 3/8-inch-diameter washed pea gravel should be placed over the washed underdrain gravel before the filter medium is added.

The filter basin can be a lined excavation or fabricated tank. For single-home systems, prefabricated concrete tanks are commonly used. Many single-home filters and most large filters are constructed within lined excavations. Typical liner materials are polyvinyl chloride and polypropylene. A liner thickness of 30 mil can withstand reasonable construction activities yet be relatively easy to work with. A sand layer should be placed below the liner to protect it from being punctured if the floor and walls of the excavation are stony. The walls of the excavation should be brought above the final grade to prevent entry of surface water.

Filters can be covered or buried. It is often necessary to provide a cover for the filter surface because the surface of a fine medium (e.g., sand) exposed to sunlight can be fouled with algae. Also, there may be concerns about odors, cold weather impacts, precipitation, leaf and debris accumulation, and snowmelt. In addition, the cover must provide ample fresh air venting. Reaeration of the filter medium primarily occurs from the filter surface. The lower 20 percent of the medium's depth maintains a high moisture content. At the bottom, the medium is near or at saturation, which is a barrier to air flow and venting from the underdrain system. The gravel surrounding the distribution piping must be vented to the surface to provide a fresh air flow. ISF filters open to the surface are built with roofs or removable covers or are merely shaded. Roofs provide cold weather protection and shed precipitation, debris, and snowmelt that would otherwise enter the system.

Performance

Treatment field performance of single-pass intermittent sand filters is presented in table 2. Typical effluent concentrations for these single-family wastewater treatment systems are less than 5 mg/L and less than 10 mg/L for BOD and TSS, respectively. Effluent is nearly completely nitrified but some variability can be expected in nitrogen removal capability. Controlled studies generally find typical nitrogen removals of 18 to 33 percent with an ISF. Fecal coliform removal ranges from 2 to 4 logs (99 to 99.99 percent). ISF fecal coliform removal is a function of hydraulic loading, with reduced removals as the loading rate increases above 1 gpm/ft^2 (Emerick et al., 1997). Effluent suspended solids from sand filters are typically low. The media retains the solids. Most organic solids are digested by the media over time.

Table 2. Single-pass intermittent sand filter performance

Reference	BOD(mg/L) Influ.	Efflu.	(% Removal)	BOD(mg/L) Influ.	Efflu.	(% Removal)	BOD(mg/L) Influ.	Efflu.	(% Removal)	BOD(mg/L) Influ.	Efflu.	(% Removal)	BOD(mg/L) Influ.	Efflu.	(% Removal)
Cagle and Johnson, 1994 [a] (California)	160	2	(98.75%)	73	16	(78.08%)	61.8	5.9	(90.45%)	61.8	37.4	(39.48%)	1.14E+05	1.11E+02	(99.90%)
Effert et al., 1985[b] (Ohio)	127	4	(96.85%)	53	17	(67.92%)	-	-	-	41.5	37.5	(9.64%)	2.19E+05	1.60E+03	(99.27%)
Ronayne et al., 1982[c] (Oregon)	217	3	(98.62%)	146	10	(93.15%)	57.1	1.7	(97.02%)	57.5	30.3	(47.30%)	2.60E+05	4.07E+02	(99.84%)
Sievers, 1998[d] (California)	297	3	(98.99%)	44	3	(93.18%)	37	0.5	(98.65%)	37.1	27.5	(25.88%)	4.56E+05	7.30E+01	(99.98%)

[a] Sand media: es = 0.25-0.65 mm; uc = 3-4. Design hydraulic loadings = 1.2 gpd/ft^2 based on 150 gpd/bedroom. Actual flows not measured.
[b] Sand media: es = 0.4 mm; uc = 2.5. Average loadings = 0.4 gpd/ft^2 / 0.42 lb BOD/1,000 ft^2. Doses per day = 3.3.
[c] Sand media: es = 0.14-0.30 mm; uc = 1.5-4.0. Average loadings = 0.33 gpd/ft^2 / 0.6-1.27 lb BOD/1000 ft^2 per day.
[d] Sand media: not reported; uc = 3-4. Design hydraulic loadings = 1. gpd/ft^2. Daily flows not reported.

Management needs

Construction of ISF units usually involves excavation, forming/framing, liner placement with supporting sand layers, and plumbing. ISF units should never be placed in surface depressions without thoroughly sealing against prolonged inundation and drainage configurations that prevent stormwater entry. In all cases, units must be watertight with sealed entries and exits for piping. Filter fabric should not be used at any location through which the filtrate would flow. Media delivered to the site should be tested against design-sizing specifications. Excess (3 percent or greater) fines are one of the greatest concerns of the construction inspector.

The operation and maintenance requirements of packed bed filters are few and simple. As with all treatment systems, flow monitoring should be conducted to identify excessive flows and check dose volumes and dosing rates. If the flows are excessive, the source of the flows should be identified and corrective measures taken. Reduced dose volumes or dosing rates suggest that the distribution network is plugged or the pump is not performing properly. The distribution network should be flushed annually (or more often, as necessary) using the manual flushing device. Also, the dosing pump should be recalibrated at least annually.

The filter surface should not pond if the filter is designed properly and the wastewater characteristics do not change significantly. If standby cells are not available for regular resting and the surface is not covered with pea gravel, the surface can be raked to break up any material clogging the filter surface. Reducing the dose volume and increasing the dosing frequency may help to increase the reaeration potential and reduce clogging of the media. If the ponding problem persists, however, removal of the top layer or complete replacement of the media may be necessary. Before replacing the media, monitor wastewater flows and concentrations to determine if they are the cause of the problem. Problem sources should be identified and addressed before repairs are effected. Premature clogging is often traceable to excess TSS and BOD loading or to fines in the media. Where the problem develops naturally over time and standby cells are available, resting may be used to supplement the raking and/or surface skimming steps.

Free-access ISFs should be checked regularly (at least every 3 to 4 months), to prevent surface problems. Periodic raking and resting is recommended to maintain percolation and prevent ponding. Scraping off the top layer (e.g., 1 inch) of sand helps to prevent clogging. Intervals between scraping vary from a minimum of 3 months up to greater than 1 year. Removed surface layers need not be replaced until the total filter depth falls below 18 inches. If new filter material is not readily available, it may be cost-effective to clean and reuse the old filter material. Resting is considered the best rehabilitation approach due to possible clogging contributions from raking/scraping.

ISFs have low energy requirements compared with other systems offering comparable effluent quality. Free-access ISFs using pumped dosing would require approximately 0.3 to 0.4 kWh/day.

Risk management issues

ISF filters are simple in design and relatively passive to operate because the fixed-film process is very stable and few mechanical components are used. High flow variations after equalization in a septic tank are not a problem because the residual peaks and valleys are absorbed in the pressurization tank or in the last compartment of the preceding septic tank. Although ISFs have biological properties, the impact of toxic loading shocks are not well documented.

Free-access ISFs are often installed with removable covers to regulate temperatures in cold climates and to reduce odors. Space of 12 to 24 inches (30 to 61 cm) should be allotted between the sand surface and the installed cover (EPA, 1980). Odors from free-access filters treating septic tank effluent may warrant installation away from dwellings, especially if spray nozzles are used in distribution.

Power outages will impact ISF systems if these systems are uniformly dosed with pumps. During the power outage, all wastewater generated will accumulate in that dosing facility and septic tank, increasing the potential for odors.

Costs

Filter media is the most expensive component in ISF construction. Typically, filter media can be installed for $10 to $15 per square foot, depending primarily on the type of media and the contractor's experience with ISF construction. Operation/maintenance costs include electricity for pumping/dosing, and 3 to 6 hours of semiskilled management visits per year cost about $150 to $200. The electricity is about $10 to $20 of that total.

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